Scattering and Reverberation Uncertainty in Shallow Water Environments due to Environmental Variability

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LONG-TERM GOALS

To quantify sonar uncertainty in the common tactical environmental picture. As a member of the seafloor uncertainty team quantify the effects of seafloor uncertainty on propagation, scattering and reverberation.

OBJECTIVES

Propagate uncertainty in the background and statistical properties of the bottom through to corresponding measures of the uncertainty of scattering strength, propagation and reverberation.

APPROACH

Working closely with the geophysicists, hydrographers and experimental geoacousticians on the seafloor uncertainty team, obtain and propagate quantitative estimates of bottom parameter uncertainty through to propagation, scattering and reverberation uncertainty using high fidelity time domain models developed at SACLANTCEN and NRL. Statistical realizations of heterogeneous seafloor sound speed are provided by John Goff (UTIG), with input on sediment surficial sound speeds measured by Barbara Craft and Larry Mayer (UNH). Bottom scatter strength and reflection measurements and associated uncertainty are provided by Charles Holland (ARL/PSU).

WORK COMPLETED

In the FY02, a statistical method for predicting the uncertainty of shallow water waveguide propagation under the adiabatic approximation in the frequency domain [1] was extended to treat uncertainty in time domain propagation and reverberation [3,4] using the narrowband approximation. Estimates of reverberation uncertainty were built upon a coherent model for reverberation developed at SACLANTCEN [2]. The results showed that bottom uncertainty induced uncertainty most strongly in the late time multipath arrivals, whereas oceanographic uncertainty most strongly affected axially propagating earlier arrivals.

In FY03 the qualitative behaviors seen in the adiabatic predictions during FY02 were confirmed using fully coupled models for propagation (C-SNAP [5]) and reverberation (R-SNAP [6]). In addition, the volume scattering extension to OASES was reported this year and this tool was used to predict the

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uncertainty of scattering strength estimates for use in estimating the observability of scattering strength parameters.

RESULTS

Scattering Strength Uncertainty

The uncertainty of the scattering cross section predictions and measurements was addressed through a modeling study using volume scattering OASES and through the analysis of scattering data collected by Charles Holland. In Fig. 1 the pdf of scattering strength estimates for a site on the Malta Plateau south of Sicily is shown for the frequencies of 1200, 1800 and 3600 Hz. This underlying measurement uncertainty is dependent on sample size; here the number of experimental snapshots of the scattering strength was 11. The pdfs for the mean of the experimental measurements were estimated using the bootstrap resampling theory [7]. The result shown in the left panel was obtained assuming perfect knowledge of the experimental geometry, while the result shown in the right panel assumed a standard deviation of ±1 m. The standard deviation of the scattering strength estimates decreases roughly proportional to the square-root of the sample size. These results show that experimental considerations can often impose a significant uncertainty on the scattering strength estimate.

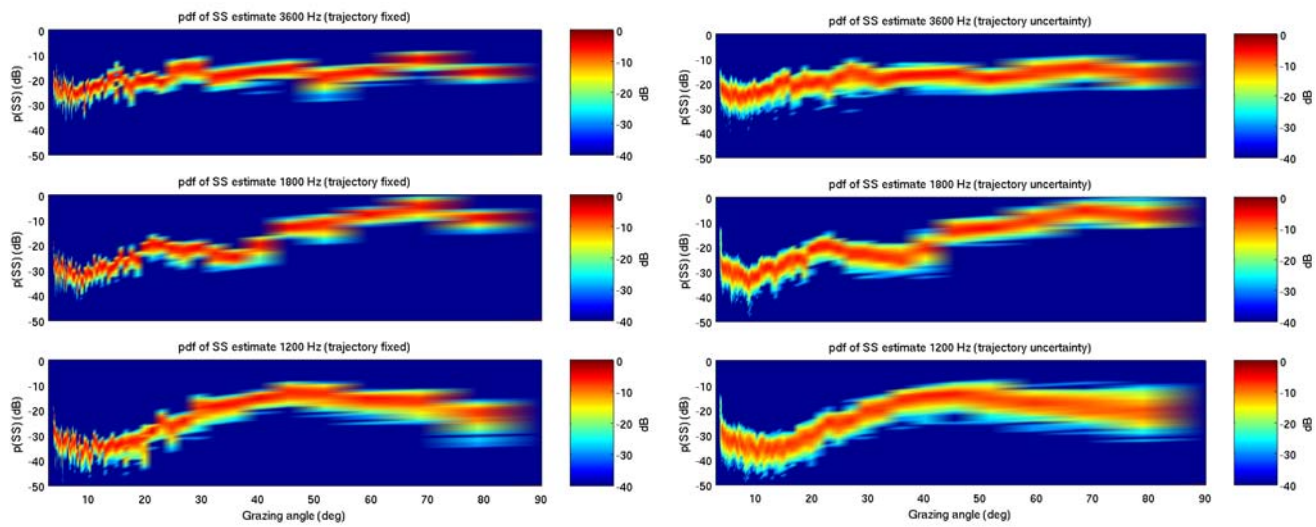

Figure 1. pdf of scattering strength estimates at 1.2, 1.8 and 3.6 kHz for a site on the Malta Plateau. Left panel shows pdfs assuming perfect knowledge of experimental geometry. Right panel assumes that experimental geometry is uncertain with a standard deviation of 1 m.

Scattering strength modeling studies were conducted in parallel to the experimental analysis in order to understand the resolvability of the mean and stochastic properties of the bottom based on sample estimates of scattering strength such as illustrated in Fig. 1. In Fig. 2 the mean and standard deviation of three scattering strength estimates obtained using the OASES volume scattering implementation are shown. Two of the results (shown in green and red) are predictions for scattering from volume inhomogeneities in a layer in a stratified bottom with properties measured at the Malta Plateau site. These two predictions differ by a background sound speed in the scattering layer of 5 m/s. The blue curve is a scattering strength prediction for a simpler half-space characterization of this bottom.

Results indicate that all three scattering strength estimates are not resolvable from one another for the sample size of the mean estimate (here 16 samples). The OASES predictions are estimates of the probability of an observation (of scattering strength, as a function of frequency and grazing angle) conditioned on a hypothesized model of the background and stochastic properties of the bottom. These likelihoods are being utilized in current work to form Bayesian estimates of the *a posterior* pdfs over the model space conditioned on experimental observations at a limited number of frequencies/angles. Such conditioned pdfs will be used in FY04 to obtain model-based estimates of the uncertainty of scattering strength estimates for other unmeasured frequencies and/or bistatic angles.

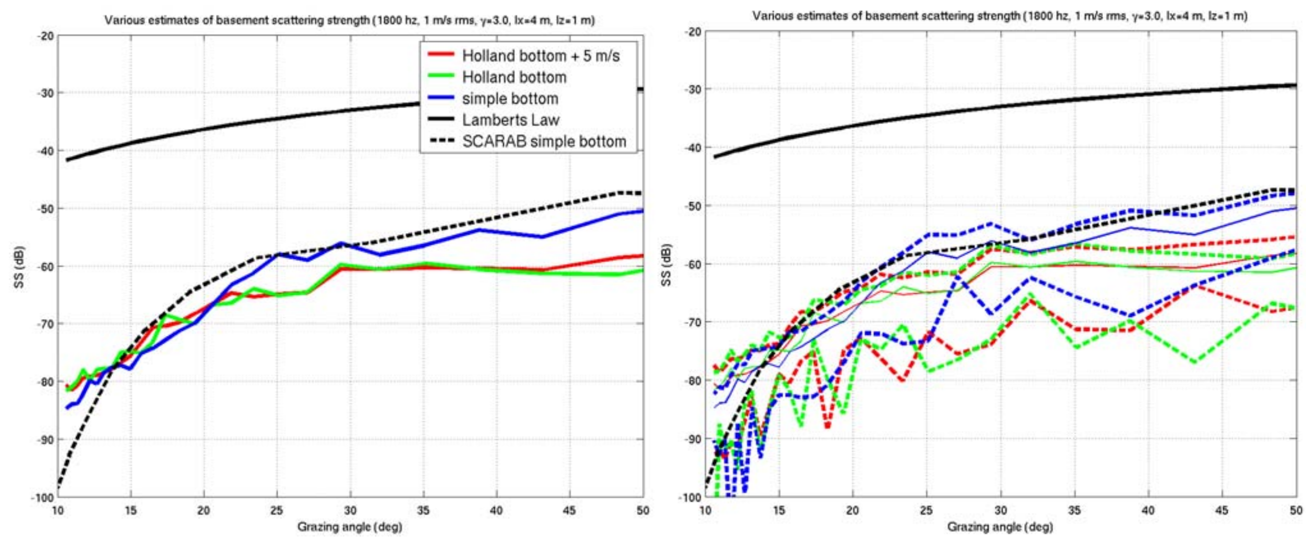

Figure 2. Mean (left panel) and standard deviation (right panel) of scattering strength estimates derived from OASES predictions of volume scattering realizations for the Malta Plateau site. The green and red curves show predictions for stratified bottom differing by 5 m/s, while the blue curve shows the predictions for an equivalent half-space bottom. The black dashed curve is a model prediction for the simple bottom obtained with SCARAB, and the black solid line is Lamberts law.

Reverberation Uncertainty

Reverberation uncertainty was estimated for waveguides with unmodeled fine scale sediment heterogeneity and uncertain scattering strength. The estimated pdf of the scattering strength measurement error for the Malta Plateau site was combined with the pdf of the angle-amplitude spectrum of modeled propagation through different types of environmental heterogeneity for the purpose of estimating the pdf of reverberation predictions.

Oceanographic Uncertainty

In the left hand panel of Fig.3 a shallow water internal wave field generated by the PROSIM package [9] is shown with the mean removed. In the right hand panel an estimate of the resulting pdf of the reverberation intensity is shown. The reverberation intensity realizations used to estimate the pdf are obtained by using the C-SNAP model for various realizations of propagation through the internal wave field. At every range the field at the scattering depth is decomposed into up and down-going plane waves in order to generate a pdf of the spectral amplitudes of the field incident on the scatterers. The angle-intensity pdf of the incident field is combined with the scattering strength pdf through a sampling strategy to calculate the pdf of the reverberation intensity. A factor $r^{-3/2}$ has been removed the resulting reverberation pdf to reduce the dynamic range. These results show that for internal wave activity corresponding to an energy level of 1 GM, the total support of the reverberation pdf is generally predicted to be less than 2.5 db at 3.7 kHz for times beyond approximately 5 s.

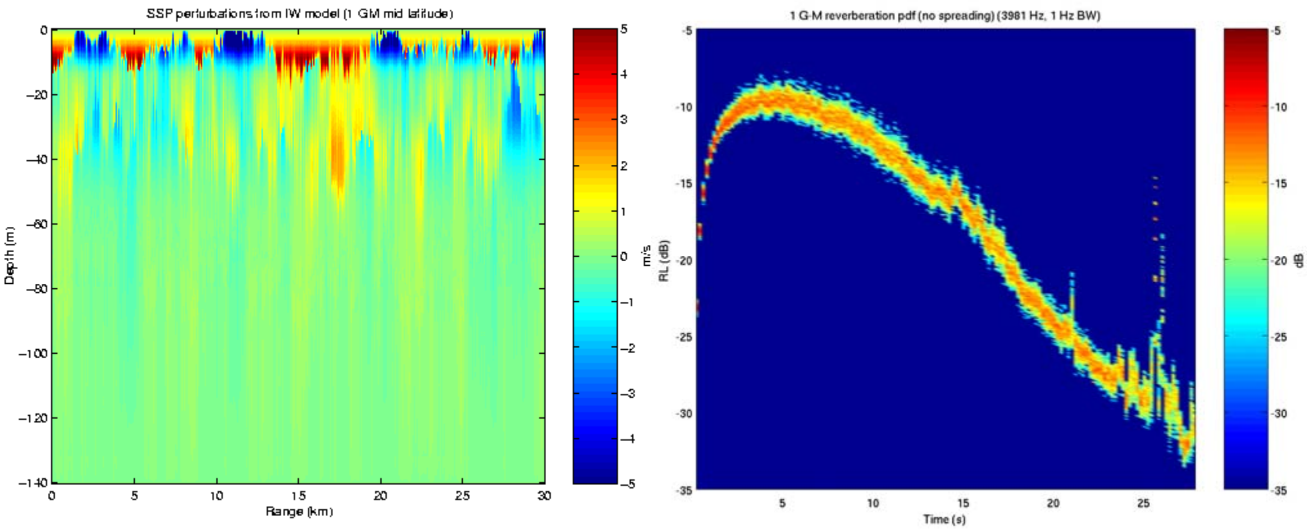

Figure 3. Internal wave realization (left panel) and resulting reverberation pdf (right panel) for a shallow water environment with the scattering strength uncertainty shown in the upper right panel of Fig. 1. Frequency is 3.7 kHz.

Bottom Uncertainty

In Fig. 4 a stochastic realization of the sediment sound speed at the New Jersey STRATAFORM site is shown. This realization was generated by John Goff at UTIG using measurements of sediment surficial sound speed collected at various locations on the NJ STRATAFORM site by Barbara Craft and Larry Mayer of UNH as inputs. The rms sound speed variance was found to be 31 m/s with a background sound speed of 1730 m/s. The horizontal correlation length scale was determined to be 12.6 km through variogram analysis of the data, and the corresponding 2-D fractal dimension was found to be 2.7. The vertical correlation length scale was not measured and was set at 5 m. Since the mean sound speed of this sediment realization was quite fast, it was assumed that there would be relatively little propagation uncertainty and little corresponding uncertainty in the reverberation. However the high fractal dimension of the sound speed defects in the sediment caused a significant number of slow regions with rather significant bottom penetration, which caused correspondingly large defects in the incident field spectrum. The support of the resulting reverberation pdf, shown detrended by the factor $r^{3/2}$ in the right hand panel of Fig. 4, is less than 1 dB at 3.7 kHz.

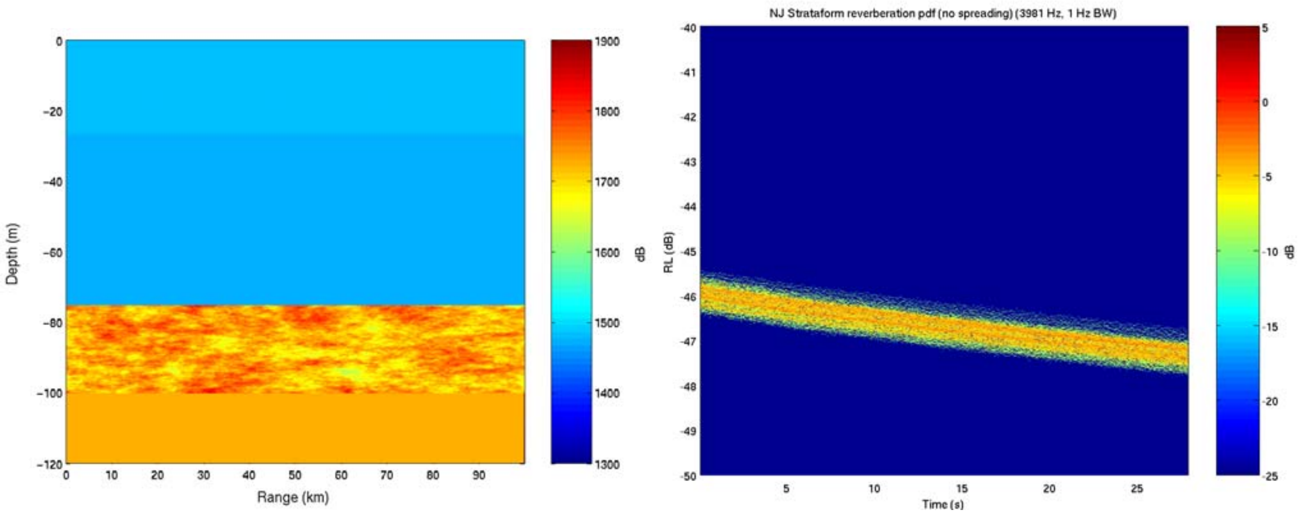

Figure 4. Stochastic realization of bottom sound speed for the NJ STRATAFORM site (left panel) and corresponding reverberation uncertainty pdf at 3.7 kHz (right panel).

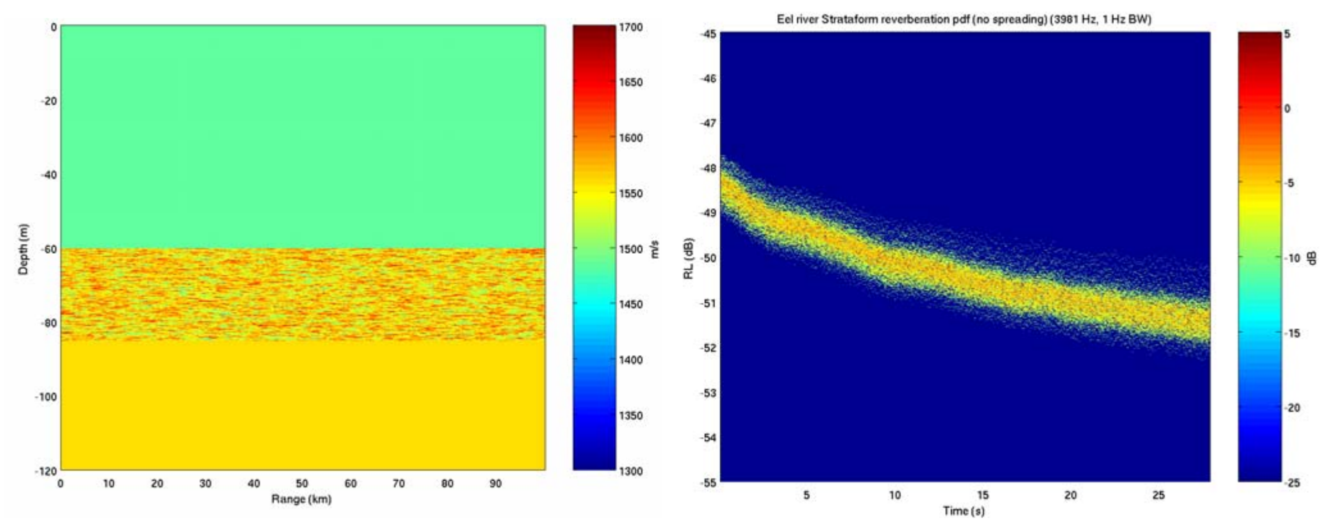

Figure 5. Stochastic realization of bottom sound speed for the Eel River STRATAFORM site (left panel) and the corresponding reverberation uncertainty pdf at 3.7 kHz (right panel).

In order to evaluate the sensitivity of reverberation to heterogeneity in slower bottoms, box cores from the heterogeneous (sand and mud) Eel River STRATAFORM site were also characterized by Goff with a stochastic realization, shown in the left hand panel of Fig. 5. For this site the background sound speed was found to be only 1560 m/s, with an rms velocity of 39 m/s, a characteristic horizontal scale of 2.5 km, a vertical correlation length scale of 25 cm. The volume fractal dimension was estimated to be 3.7. The support of the reverberation pdf for this slower bottom, shown in the right hand panel of Fig. 5, was also found to be approximately 1 dB at 3.7 kHz, similar to the result for the faster sediments at the NJ STRATAFORM site.

IMPACT/APPLICATIONS

A mechanism for the prediction of scattering strength and reverberation level pdfs for uncertain shallow water environments using high fidelity models has been established. Results show that typical oceanographic and scattering strength uncertainty leads to a total support of less than 2.5 dB for the reverberation uncertainty pdf at 3.7 kHz. This is larger than the approximately 1 dB of pdf support for uncertainty induced by typical bottom variability at this frequency. This level of uncertainty is for unmodeled fluctuation components only, when the mean properties of the waveguide are known. It is anticipated that much higher levels of uncertainty may result when biases in the mean properties of the waveguide and scattering strength are introduced, as is often the case when using inaccurate environmental characterizations from databases.

TRANSITIONS

None

RELATED PROJECTS

This work has been carried out as a member of Charles Holland's (ARL/PSU) Seafloor Variability team. Other members include John Goff (UTIG), Larry Mayer, Brian Calder and Barbara Craft (UNH), James Syvitski and Irena Overeem (INSTARR), Bob Odom (APL/UW) and Lincoln Pratson (Duke). Results of ONR Uncertainty DRI funded work at ARL/PSU, UTIG and UNH have been used in the work reported here.

Reverberation modeling work reported here is also relevant to an FY03 internally funded 6.2 NRL new start entitled " Physics-based optimization of multistatic active system performance". Roger Gauss PI.

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